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Identification of Charred Wood from an Ancient Charcoal Production Site in the Black Forest of Germany

Identifikacija pougljenjenog drva s drevnog mjesta proizvodnje drvenog ugljena u Schwarzwaldu, u Njemačkoj

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ABSTRACT • *Charcoal production sites serve as palaeoarchives and contain wood charcoal, which can be identified taxonomically and be utilized to obtain information and reconstruct the past vegetation, based on the occurrence of woody taxa. In the present research, the study material was collected from the Black Forest south of Freiburg (Germany), in the Schauinsland region. Charcoal samples were gathered from the surface as well as from various depths in the soil (30 cm, 60 cm and 90 cm). The main identified taxa were Abies and Fagus, almost at the same percentage of constitution, providing evidence for their growth in the area and their selection for charcoal production. The number of growth rings and samples dimensions were measured, in order to gather information of the climatic conditions and the productivity of those past time periods.*

KEYWORDS: *archaeological wood; charred wood; charcoal assemblages; growth rings*

SAŽETAK • *Lokacije za proizvodnju drvenog ugljena služe kao paleoarhivi i sadržavaju drveni ugljen koji se može taksonomski identificirati te na temelju pojave drvenastih taksona iskoristiti za dobivanje informacija i rekonstrukciju nekadašnje vegetacije. Materijal za istraživanje prikupljen je iz Crne šume južno od Freiburga (Njemačka), u regiji Schauinsland. Uzorci drvenog ugljena prikupljeni su s površine i s različitih dubina u tlu (30, 60 i 90 cm). Glavni identificirani taksoni bili su Abies i Fagus, gotovo jednakog postotka konstitucije, što potvrđuje njihov rast na tom području i objašnjava njihov odabir za proizvodnju drvenog ugljena. Izmjereni su broj godova i dimenzije uzoraka kako bi se prikupile informacije o klimatskim uvjetima i produktivnosti u tim prošlim vremenskim razdobljima.*

KLJUČNE RIJEČI: *drvo s arheološkog nalazišta; pougljenjeno drvo; nalazišta drvenog ugljena, godovi*

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1 INTRODUCTION
1. UVOD

Wood as a raw material has been exploited by mankind since its appearance on earth and contributed not only to its survival but to the establishment of civilization as well (Tsoumis, 1983). During industrial revolution, wood was massively used in the form of charcoal for the production of energy. As a result, many charcoal production sites were established all over the forests of Europe. The locations and studies of these sites provide valuable information about the composition of the vegetation in the past, in terms of wood species and timber production taxa (Braadbaart and Poole, 2008; Figueiral and Mosbrugger, 2000; Gocel-Chalté *et al.,* 2020). In the Mediterranean region, wood exploitation for charcoal began over two thousand years ago and had almost completely ceased by the late 19th century. Many kiln sites are located in forests dominated mainly by oak, due to their large size, as well as by beech and other types of forests (Carrari *et al.*, 2017).

Archaeological charred wood can be described as a non-active, black material that has been exposed to temperatures that exceeded 350 °C for a duration of 15 minutes and was turned into charcoal due to either carbonization without oxygen or incomplete charring with a very low presence of oxygen (Braadbaart and Poole, 2008). Analysis of charcoal includes the examination and identification of wood remains based on the observation of the anatomical characteristics of wood in three-dimensional form (Kabukcu *et al.,* 2018).

Charcoal assemblages can be studied and identified based on their structure, which remains largely intact in quality when wood is incompletely combusted, as the anatomical features are not significantly altered (Koeppen, 1972; Beall *et al.,* 1974). Furthermore, in the case of large samples, the width of the growth rings can be measured as well. The data obtained can reveal the selection of wood species used for energy production in the past (Marguerie and Hunot, 2007). The identification can be implemented with various techniques depending on the study material and available equipment such as reflected light microscopy or 3D-reflected light microscopy (3DRLM) and field emission scanning electron microscopy. However, 3DRLM has proved to be more effective for charcoal identification (Zemke *et al*., 2020). The surface quality is critical, since in most cases charcoal findings are handled as they are with no previous preparation, giving only partial areas that are in focus. Although significant differences in surface roughness have been recorded among different trees, not significant differences have been detected between heartwood and sapwood or in different heights of a tree (Chavenetidou and Kamperidou, 2024).

Fragments of charcoal are buried in the soil or even lay on its surface and are found easily all over the world. Charred wood is not so sensitive to microbial attack and can preserve its natural wood anatomy. Thus, its analysis is a cornerstone for paleoenvironmental science (Nelle *et al.,* 2013). The analysis of charcoal in the aspect of taxonomic classification was applied during the 19th century, though it was mostly developed in the 1970's (Thinon, 1978). Charcoal identification can provide knowledge about climatic changes of the past. The identification is based on the knowledge of the macroscopic and microscopic features of wood, which constitute its structure and anatomy (Koeppen, 1972; Wheeler and Baas, 1998).

In most cases, charcoal findings are of small dimensions, reaching a size of several centimeters. However, there are cases where larger parts of buildings and constructions have been found, giving the opportunity to obtain additional information. For instance, the findings of excavations around Naples (southern Italy) suggest that mainly conifers were selected as a building material, such as *Abies alba* and *Cupressus sempervirens*, species that nowadays are rarely found or, in the case of cypress, almost extinct from Naples and Italy. Moreover, the collected samples of *Larix* and *Picea abies* indicate the import of wood from foreign countries (Moser *et al.,* 2018).

Anthracological studies may reveal the existence of woody plants in the past but also provide information about the evolution and the changes of the environment, as well as the way people interacted with it. In France, the studies suggest that the species chosen for fuel production were selected according to their technical features, such as oak, as well as their availability (Marguerie and Hunot, 2007). In Germany, charcoal findings dated to High and Late Medieval Times as well as Roman Iron Age indicate that the dominant species was *Quercus*, followed by significant percentage of *Ericaceae*. At the top layers, which are regarded to be younger, various species were found, including *Quercus, Fagus, Betula, Alnus, Fraxinus, Corylus, Salix, Acer*, *Pinus* and others in smaller proportions (Jansen *et al.,* 2013). Moreover, the analysis of charred wood can lead to findings related to the interaction of natural and anthropogenic environment. In the case of research in Harz Mountains (Germany) kiln sites, the findings suggest that the species used for energy production were determined by the topography of the area and the available wood species, rather than by selection (Knapp *et al.,* 2015). Even today, a large portion of wood production is still used for charcoal manufacturing, according to FAO (2017). Research by Haag *et al.* (2020) examined 150 charcoal samples from 11 countries in Europe and found that a significant share of timber originated from tropical and subtropical species (approximately 46 %), while the remainder came from Europe timber species. The study highlights the necessity to include charcoal into the scope of European Timber Regulations (EUTR).

There are cases where the disappearance of forests is attributed to humans. In Tibet (China), anthracological analyses revealed the existence of tree and shrub vegetation, which consisted mostly of *Juniperus, Salix, Betula* and *Hippofae*. At present, this area is similar to the desert with grasses and small herbs (Kaiser *et al.,* 2009).

Since the analysis of charcoal is influenced by various factors, the connection with data from other sectors of science combining geomorphological, archaeological and palaeobotanical data is necessary for more accurate conclusions (Jansen *et al.,* 2013; Knapp *et al.*, 2015). Moreover, the preservation of charred wood is a result of climatic as well as anthropogenic factors that affect its mechanical, physical and chemical properties. Decayed wood charcoal has less mechanical resistance than undecayed wood charcoal. However, most species exhibit similar properties, when transformed to charcoal, with only minor differences observed between conifers and broadleaved trees (Braadbaart and Poole, 2008; Théry-Parisot *et al.,* 2010).

The combination of charcoal analysis and dendrochronological estimations provide more detailed assessment of former conditions and vegetation, as well as the evolution of the landscape. Thus, the presence or absence of specific species can be identified in areas where kiln sites were established. In northern Belgium, where such sites were located and dated at 1300-1900 AD, the main species used for charcoal production was alder probably from coppice stands, when the dominant vegetation consisted of oak trees, probably due to conversion of woodland to grassland (Deforce *et al.,* 2013). Charred wood from the late Holocene was investigated in Bosnia- Herzegovina to reveal various genera with the most dominant those of *Quercus, Ostrya, Carpinus, Acer, Fagus* and *Pinus* (Schroedter *et al.,* 2013). In Alpine and Subalpine areas of Trentino (Italy), during the Holocene a forest expansion was detected, according to studies, at the Lateglacial around 10 500 cal. BP with *Pinus sylvestris, Pinus mugo* and *Larix decidua*, whereas sites used for grazing during the Bronze Age were naturally reforested after abandonment (Favilli *et al.,* 2010).

Dendrochronology is related to tree ring measurements for the estimation of wood age. In temperate zone, the growth rings of a tree show a periodicity in their formation, which in most cases reflects the annual cycle of growth, thus enabling the estimation of wood age. The rings are not of the same width, reflecting the environmental conditions (mainly rainfall and temperature) of each growth period. Species grown in specific geographic area are exposed to similar environments, so their tree-ring series can be cross dated and provide chronologies for dating and for calibration of the radiocarbon dating method (Creber, 1977; Schweingruber, 2012). Radiocarbon dating is a technique based on the analysis of carbon ^{14}C in biological matter and provides more accurate results when it comes to charcoal remains, which usually have small dimensions and not many obvious growth rings. However, in some cases (Rybníček *et al.,* 2022) charcoal dating with radiocarbon technique can be insufficient. Wood is suitable for the application of this method, especially because it enables the use of wiggle-matching method.

The aim of this research was a detailed analysis and identification of charred samples from charcoal production site K600 in Black Forest, Schauinsland region, from the period of late medieval to early modern times, as an effort to enrich the archaeological archives of charcoal in Germany and contribute to the botanical mapping of the past. Furthermore, a study of the anatomical characteristics and the growth rings of the samples was implemented.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The research material was collected from the Black Forest south of Freiburg (Germany), in the Schauinsland region (Figure1), during a field trip to the area. The charcoal findings were attributed to the late medieval/early modern times charcoal production sites in Baden-Württemberg.

After digging the soil, sampling material was collected at different depth profiles (0-30cm, 30-60 cm, 60-90 cm) including surface samples (Figure 2) in order to identify the species and see the evolution of their exploitation through different periods of time.

Then, they were stored in plastic bags and in a next step they were left to dry in open boxes, until their moisture content reached the equilibrium moisture content levels related to the stable relative humidity and were easy to handle without collapsing (Figure 3).

The charred wood was broken with a sharp knife, so as to have freshly broken surfaces (transversal, radial and tangential) and be easily observed in reflectance light microscope equipment with a stereo lens and a microscope (Figure 4). After identification, the samples were preserved in paper envelopes.

The estimation of the age of the trees used to produce charcoal was conducted based on the circle tool for the estimation of wood diameter size (Ludemann, 2006; Pişkin *et al.,* 2018). At the same time, growth rings number estimation was conducted during microscopic observation of the largest samples.

An estimation of the age of charred wood is also possible with the use of a circle tool that represents a cross section of the tree (Figure 5). Depending on the

Figure 1 Research area of Black Forest in Germany (https://www.worldatlas.com/maps/germany, https://www.schauinsland.de/museums-bergwerk/wp-content/uploads/2019/09/anfahrtsskizze.jpg)
Slika 1. Područje istraživanja Crne šume u Njemačkoj (https://www.worldatlas.com/maps/germany, https://www.schauinsland.de/museums-bergwerk/wp-content/uploads/2019/09/anfahrtsskizze.jpg)

a)

b)

c)

Figure 2 Fieldwork: a) digging, b) pit depth, c) collection of samples
Slika 2. Terenski rad: a) kopanje, b) određivanje dubine jame, c) prikupljanje uzoraka

a) b)

Figure 3 a) storage of samples, b) placement in open boxes for drying out
Slika 3. a) Skladištenje uzoraka, b) stavljanje uzoraka u otvorene kutije za sušenje

a) b)

Figure 4 Observation with the use of a) sterescope Nikon SMZ1270, b) microscope with an attached camera Nikon DS-Ri2 (Nikon Eclipse LV100ND)
Slika 4. Promatranje uzoraka: a) stereoskopom Nikon SMZ1270, b) mikroskopom s kamerom Nikon DS-Ri2 (Nikon Eclipse LV100ND)

curves of the growth rings, the dating of the charcoal sample is possible, atlthough not so accurate (Pişkin *et al.,* 2018).

The statistical analysis of the results was performed by using IBM SPSS software, version 23 (IBM, 2015) and an analysis of Variance (Anova) was implemented as well as a Kolmogorov-Smirnoff test, so as to identify whether any differences were stastitically important.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

In total, 113 charcoal assemplages were examined from different soil depths of the study area (Table 1). The main identified genera were *Abies* and *Fagus* (Figure 6).

Figure 6 a, b shows a charcoal sample of conifer tree, with no resin canals, uniserate rays with absence of radial tracheids. Based on the distribution of the species in the past area, the dominant conifer tree with such wood anatomy is *Abies alba* (Schweingruber, 1990). Figure 6b depicts a diffuse porous hardwood with small vessels, which are slightly larger in

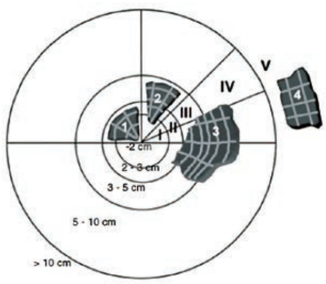

Figure 5 Circle tool for the estimation of wood diameter size applied in an anthracological sample (Ludemann, 2006; Pişkin *et al*., 2018)
Slika 5. Kružni alat za procjenu promjera drva antrakološkog uzorka (Ludemann, 2006.; Pişkin i dr., 2018.)

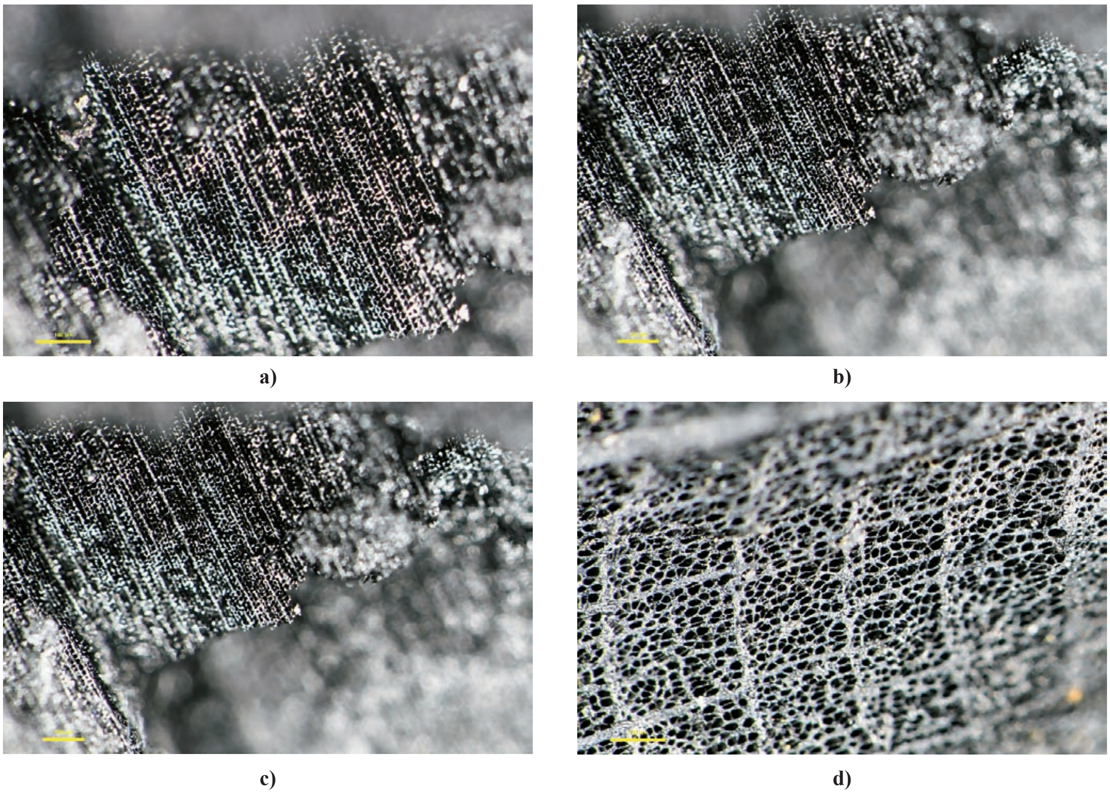

Figure 6 Stereoscopic pictures of transverse sections of: a), b) *Abies*; c), d) *Fagus* (bar = 100µm)
Slika 6. Stereoskopske slike poprečnih presjeka: a) i b) *Abies*; c) i d) *Fagus* (oznaka = 100µm)

Table 1 Total number of charcoal samples
Tablica 1. Ukupan broj uzoraka drvenog ugljena

K600 samples / *K600 uzorci*	**Sample descriptipn** / *Opis uzoraka*	***N***	***Abies***	***Fagus***
K600a	Samples collected from the surface before digging were seperated in two categories based on their size. *Uzorci prikupljeni s površine prije kopanja podijeljeni su u dvije kategorije na temelju njihove veličine.*	20	11	9
K600b		19	12	7
K600 – surface	Samples collected from the surface after digging. *Uzorci prikupljeni s površine nakon kopanja.*	16	5	11
K600_profile_0 – 30 cm	Samples from the material collected at different depths and after drying in the lab. *Uzorci prikupljenog materijala s različitih dubina i nakon sušenja u laboratoriju.*	20	5	15
K600_profile_30 – 60 cm		20	13	7
K600_ profile_60 – 90 cm		17	7	10
N_Total / *ukupno*		112	53	59

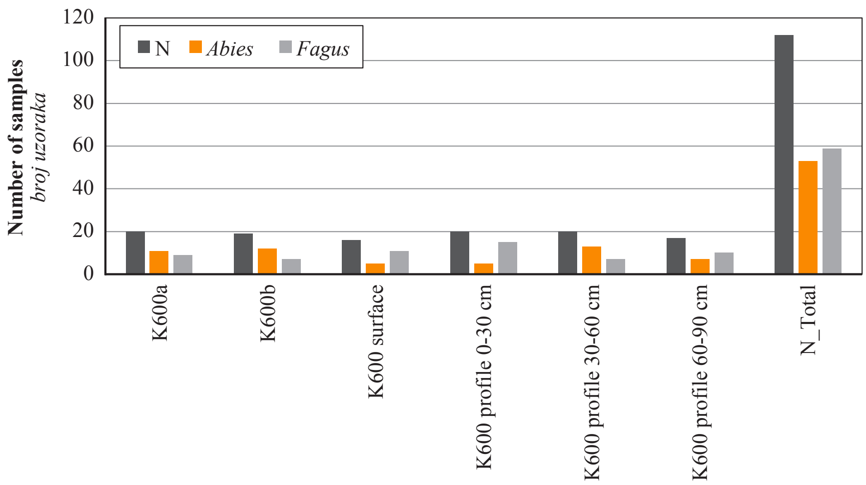

Figure 7 Distribution of species among charred wood samples
Slika 7. Raspodjela vrsta drva pougljenih uzoraka

Table 2 Analysis of variance for data collected
Tablica 2. Analiza varijance prikupljenih podataka

Analysis of variance / *Analiza varijance* (ANOVA)						
		Sum of squares *Zbroj kvadrata*	*df*	Mean square *Srednji kvadrat*	*F*	Sig.
Abies	Between groups / *među grupama*	1702.190	4	425.548	24.551	.040
	Within groups / *unutar grupa*	34.667	2	17.333		
	Total / *ukupno*	1736.857	6			
Fagus	Between groups / *među grupama*	2082.190	4	520.548	30.032	.032
	Within groups / *unutar grupa*	34.667	2	17.333		
	Total / *ukupno*	2116.857	6			

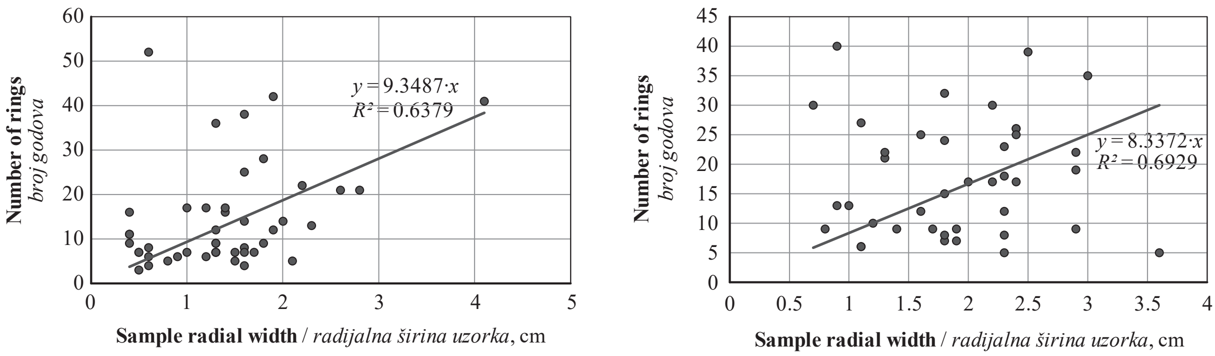

Figure 8 Graphical distribution of the number of rings per sample, in relation to radial width of the sample: a) *Abies*, b) *Fagus*
Slika 8. Grafička raspodjela godova po uzorku s obzirom na radijalnu širinu uzorka: a) *Abies*, b) *Fagus*

the earlywood, either solitary or in clusters, and often with tyloses, multiseriate rays of two sizes, i.e. 3-5 cells wide or more than 10 cells, and distinct growth ring boundaries. Based on wood anatomy features, the sample corresponds to *Fagus* sp. in the sampling area represented by *Fagus sylvatica* (Schweingruber, 1990).

According to the following table, 112 samples were studied in total. *Abies alba* (European silver fir) was detected in 53 of them, whereas the rest 59 were *Fagus sylvatica* (European beech) (Figure1).

The findings are in line with previous studies, since *Fagus sylvatica* and *Abies alba* were two of the dominant species in the area of Black Forest in the postmedieval times. (Ludemann, 2010).

According to Figure 7, the depth was not a factor of influence on the selection of wood species, since no certain tendency of the species appearance was observed.

Analysis of variance (ANOVA) showed that there are statistically significant differences between groups in the values of the variable for the species *Abies* (F = 24.551, p = 0.040) and *Fagus* (F = 30.032, p = 0.032). The F values (24.551 and 30.032) are quite high, meaning that the variation between groups is much greater than the variation within groups.

When small samples, meaning those with a small radial width, contain many growth rings, this may indicate a period of slow growth in the past, or that the samples originated from branches, which typically have a different structure compared to the trunk. In the case of *Abies*, the tendency noticed is that small samples include lower number of growth rings. On the other hand, in *Fagus* a greater distribution is observed. In case small charcoal samples include a great number of growth rings, this might indicate that charcoal was made from branches. However, R^2 is very low in both cases, and they do not demonstrate any clear trend.

4 CONCLUSIONS
4. ZAKLJUČAK

Charcoal production sites function as palaeoarchives and contain wood charcoal that can be taxonomically identified to provide information about past vegetation. In a case study conducted in the Black Forest, south of Freiburg (Germany), charcoal remains dated to the late medieval and early modern periods indicate that the dominant species used for charcoal production were *Abies alba* and *Fagus sylvatica*, as identified in the charcoal assemblages. Depth of sampling did not significantly affect species proportions. Tree ring width varied considerably but showed no correlation with sample size. Precise measurements of tree ring width and number, along with their absolute dating, other proxies (e.g. pollen analyses) and broader sampling could provide more comprehensive insights into vegetation in the area during the specific time period.

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